Characterization of Textile Dyeing Effluent and Removal Efficiency Assessment of Al$_2$(SO$_4$)$_3$ Coagulant

Md. Abu Sayed[1] & M.G. Mostafa[2*]

[1,2]*Water Research Laboratory, Institute of Environmental Science, University of Rajshahi, Rajshahi 6205, Bangladesh. Corresponding Author (M.G. Mostafa) Email: mgmostafa@ru.ac.bd**

ABSTRACT

The textile dyeing industry discharges a variety of effluents into nearby surface water bodies, which pose a threat to the environment. The study aimed to characterize the effluents and evaluate the coagulant efficiency of Al$_2$(SO$_4$)$_3$ for the treatment of textile effluent. This investigation deals with studying the parameters affecting coagulation-flocculation (C-F) behavior, such as coagulant dose, reaction time, pH, and temperature, using a jar test apparatus. The analyzed parameters before and after treatment are pH, dissolved oxygen (DO), electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD), and some anions. The analysis results showed that the textile dyeing effluent was highly alkaline, and parameters like EC, TSS, TDS, COD, BOD, and some anions were found to be higher than the DoE-BD standard guidelines for effluent discharge, indicating that the effluents are loaded with high amounts of organic and inorganic pollutants. The study optimized the process parameters of the coagulation The study optimized the process parameters of the coagulation, which illustrated that the Al$_2$(SO$_4$)$_3$ coagulant potentially reduced pH, EC, TDS, TSS, BOD, and COD from the effluents. The study observed that the highest removal of COD and BOD was 66% and 74% for the samples Ef2 and Ef3, respectively. The highest TSS removal rate was around 90% for Ef3, and almost 80% TDS removal was achieved for all effluents. The results indicated that Al$_2$(SO$_4$)$_3$ showed a better coagulant efficiency for reducing the concentration of several physicochemical parameters in wastewater, and the treated effluent satisfied the DoE-BD standards for discharging wastewater into the public sewage network. Hence, Al$_2$(SO$_4$)$_3$ would be a potential coagulant for treating the textile effluents that help to build a sustainable environment.

Keywords: Characterization; Dyes; Effluent; Coagulant; Treatment; COD; BOD; TDS; Removal Efficiency.

1. Introduction

Textile industrial effluent is a recalcitrant and highly toxic wastewater (Riadi et al., 2016). This wastewater is classified as hazardous waste due to its high content of non-biodegradable organic dye molecules. Dyes are mostly colored organic complex compounds that are broadly used in various industrial sectors to dye their goods. Particularly synthetic dyes are extensively used in various branches of the textile industry (Tareque et al., 2023; Halima and Mostafa, 2022; Islam & Mostafa, 2018; Slama et al., 2021), the leather industry (Chowdhury et al., 2015, 2013), the paper industry (Ivanov et al., 1996; Shakil and Mostafa, 2021a, b), the food industry (Zahedi et al., 2020), hair coloring (Scarpi et al., 1998), and so on, producing a huge volume of dyeing effluents. In textile industries, 93% of the raw water used for production comes out as strongly colored wastewater due to dyes containing high electrical conductivity, chemical oxygen demand, biological oxygen demand, a large quantity of suspended solids, total dissolved solids, extreme pH, surfactants, salts, high temperatures, concentrated organic compounds, and heavy metals (Wijannarong et al., 2013; Islam and Mostafa, 2022). Among the various contaminants released into the environment by the textile industry, dye contaminants are considered one of the most dangerous contaminants. Bangladesh, being a developing country, has been industrialized during the last two decades in various sectors. All these industries use a large variety of chemicals in considerable quantities. More than 70,000 tons of approximately 10,000 dyes and pigments are produced annually worldwide, of which approximately 20-30% are discharged as effluents from the curing and finishing processes of textiles (Patil & Shrivastava, 2015). About 20-30% of the 10,000 dyes and pigments used in the textile industry are reactive dyes

(Papić et al., 2004), which include azo, anthraquinone, phthalocyanine, formazin, oxazine, etc. The overwhelming majority of synthetic dyes currently used in the industry exhibit considerable structural diversity and due to their high molecular weight and complex structures, they show very low biodegradability (Gao et al., 2007). Wastewater discharged from the textile dyeing industry does not meet the DoE-BD standard limit. Therefore, the disposal of textile dye wastewater is an issue in densely populated areas like the Sirajganj and Tangail Districts of Bangladesh. Hence, the wastewater has to be treated prior to disposal.

There are several ways to treat dye effluent, but none of the techniques in use today are universal. Current wastewater treatment technologies include: coagulation treatment (Islam and Mostafa, 2020), coagulation and adsorption treatment (Mostafa et al., 2010; Patel & Vashi, 2010;), biodegradation (Daneshvar et al., 2007; Plooy et al., 2014; Mostafa, 2012), electrochemical degradation (Fan et al., 2008), adsorption processes (Amin et al., 2015; Mostafa et al., 2010; Mostafa and Hoinkis, 2012), ozonation, oxidation, chemical precipitation, ion-exchange, membrane filtration, and advanced oxidation processes have been known to treat the textile effluent (Mostafa et al., 2011; Chaudhari et al., 2011; Mostafa et al., 2017). However, coagulation is a common and widely used process due to its high efficiency and low cost, and has proven effective in removing colorants, especially COD from wastewater. In dye effluent treatment, dyes to be removed remain in colloids and in suspended form. These colloids are destabilized by coagulation techniques. Coagulation means the agglomeration of suspended particles by adding a chemical substance. This reduces the surface charges and forms a complex hydrous oxide. The most important surface phenomenon is the accumulation of charged particles on surfaces (Wong et al., 2007). Coagulation involves the mechanisms of ionic layer compression, charge neutralization, entrapment, and bridging. The addition of electrolyte products, such as aluminum sulfate to the wastewater produces hydrolyzable metal ions that can remove the colloidal surface charge. Negatively charged colloids are surrounded by opposite charges called counter ions that originate from the flocculant (Karlapudi et al., 2018). The opposite charges will in turn be surrounded by charges opposite them forming an electric double layer. When the concentration of ions is low, the thickness of the double layer is larger. When concentration is increased, the colloid charge will be neutralized, causing a double layer to separate. In this way, the colloids can be settled. Normally, the colloids are negatively charged, so the coagulants are usually inorganic or organic cationic coagulants with a positive charge in the water. Hence, in the present study, the most common aluminum salt used for coagulation is aluminum sulfate due to its high treatment efficiency and low cost.

Bangladesh has been industrializing over the last two decades, but few use biological process-based Wastewater Treatment Plants (ETPs) (Sabur et al., 2012; Monira et al., 2023). This process requires significant capital and foreign technology for initial setup. As a result, nearly every industry discharge wastewater into the nearest water body, reservoir, or environment without considering any mitigation measures (Saha et al., 2021; Islam and Mostafa, 2021. So, considering the present needs, this research was undertaken for the treatment of textile effluents by $Al_2(SO_4)_3$ coagulant. In this study, several selected textile dyeing wastewaters from Sirajganj and Tangail districts of Bangladesh were collected, characterized, and treated to investigate the removal efficiency of EC, COD, BOD, TSS, and TDS from the wastewater. Textile dyeing factories in Sirajganj and Tangail districts discharge untreated sewage into surrounding areas. These wastewaters, containing multiple contaminants, pose an unprecedented threat

to ecosystems, surface waters, and groundwater. Due to the adverse effects of untreated effluent on various ecosystems, the removal of pollutants has become imperative (Islam et al., 2012; Rahim and Mostafa, 2021; Shakil and Mostafa, 2023). The aim of this study was to characterize the effluents to understand their pollution level and to evaluate the efficiency of $Al_2(SO_4)_3$ coagulant in terms of EC, COD, BOD, TSS, and TDS removal from the textile dyeing effluents. In this study, the optimal coagulant dosage, optimal pH, temperature, and reaction time were identified.

2. Materials and Methods

2.1. Sample collection

Three types of textile effluent were collected directly from the outlets of three selected dyeing industries. These are named Ef1 and Ef2 from Sirajganj district and Ef3 from Tangail district, Bangladesh. Approximately 10.0 L of each sample was collected in separate plastic containers that were pre-washed with diluted HNO_3 and rinsed three times with distilled water. The samples for heavy metal analysis were preserved with HNO_3, but those for analyzing physicochemical parameters were not acidified. The collected effluents were high in color, COD, and BOD. So, the samples were wrapped in aluminum foil to prevent natural degradation by sunlight. Samples were labeled and sealed, immediately brought to the laboratory, and stored in a refrigerator at a temperature of approximately 4°C until experimentation. Untreated effluent was then analyzed for several physicochemical parameters, such as pH, DO, EC, COD, BOD, TSS, TDS, and some anions, within one week of sampling, according to standard methods prescribed by the American Public Health Association (APHA, 2017).

2.2. Sample analysis

The collected samples were immediately transported to the laboratory and analyzed for some physicochemical parameters, including pH, DO, EC, TSS, TDS, COD, and BOD. In addition, several anions, such as Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, and PO_4^{3-} were also measured. The TDS and TSS of the effluents were measured using the gravimetric oven drying method at 105°C. The BOD of the effluents was determined by incubating samples at 20°C for 5 days, followed by titration. The COD was determined by the closed reflux method. Bicarbonate, chloride, and sulfate were determined by the complexometric titration, argentometric titration, and turbidity methods, respectively. The above-mentioned parameters were also measured after treatment with $Al_2(SO4)_3$ coagulant, following the same procedures. The above parameters were measured according to the recommendations of the American Public Health Association (APHA, 2017) at room temperature. The results of the analysis of the effluent were evaluated according to the criteria laid down by the DoE- BD standards.

2.3. Sample treatment

The coagulation-flocculation (C-F) experiments were performed in jar test at the laboratory scale using the collected effluents namely Ef1, Ef2, and Ef3. Experiments were first carried out with various doses to identify the optimum dose of coagulant without changing the pH, and then the optimized dose of coagulant was used to investigate the effect of pH on COD removal. Each of the beakers was filled with the desired volume of dye effluents and dosed with the desired amount of coagulants. After the addition of the coagulant, the solution was

rapidly stirred (300 rpm) for one minute to ensure complete dispersion of the coagulant. It was then mixed slowly (45 rpm) for 30 minutes to promote floc formation and then left to stand for 30 minutes. During the study of the effect of pH on the C-F process, the pH of the initial dye solution was adjusted in the range of 3-12 before being subjected to the jar test. The pH of the effluents was adjusted with 0.1M HCl and 0.1M NaOH solutions. At the end of the sedimentation period, the supernatant was collected in the top of the beaker, and the COD of each effluent was carefully measured using the closed reflux method. The percent COD removal efficiency of the coagulant was calculated using the following equation.

$$\% \ of \ COD \ removal \ efficiency = \frac{C_0 - C_f}{C_0} \times 100 \qquad (1)$$

Where, C_0 and C_f are the initial and final COD of the untreated and treated effluents, respectively.

3. Results and Discussion

3.1. Characterization of the effluents

The effluents discharged from textile industries are a mixture of dyes, metals, and other pollutants. So, the study was targeted to characterize and treat the textile dyeing effluent before discharging it into the adjacent water bodies. The collected samples from the textile dyeing industry were analyzed for some physicochemical parameters, including pH, DO, EC, TSS, TDS, COD, and BOD to evaluate the pollution loads in water streams where the discharge effluent entered. In addition, some anions, such as Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, and PO_4^{3-} were measured in the samples. These parameters represent the pollution status of the collected effluent.

The physicochemical characteristics of the raw effluent are presented in Table 1. The EC value of the samples was almost four times higher than the DoE-BD standard indicating a large number of ionic elements present that increased the pollution level in the discharged effluents. Several studies conducted by investigators confirm the current results, with EC values ranging from 3652 to 4380 μS/cm (Dulov et al., 2011) and 4150 to 5640 μS/cm (Islam & Mostafa, 2020), whereas the EC values varied from 795 to 60200 μS/cm with an average of 14109.56 μS/cm were found in an experiment described by Sultana *et al*. (Sultana et al., 2009) on the textile effluents. The COD and BOD (two important parameters to judge the water quality) of the effluents were 3732, 3480, & 2980 mg/L, and 1156, 1065, & 964 mg/L for Ef1, Ef2, and Ef3, respectively. The findings were several times higher than the DoE-BD standard indicating that the effluents are highly loaded with organic and inorganic pollutants. Higher COD values were due to the presence of oxidizable compounds used in various steps of textiles processing. The present findings were almost similar with the study conducted by Elango et al., (2017), where BOD value was 970 mg/L and that of Imtiazuddin et al., (2012) where BOD was varied from 85.35 mg/L to 653.75 mg/L. The TSS and TDS of the effluents also cross the maximum permissible limit as shown in Table 1. Several reports showed that the TSS of some textile dyeing effluents was varied from 306 to 442 mg/L (Dulov et al., 2011), 736 to 1960 mg/L (Sultana et al., 2009), 29 to 658 mg/L (Shamim et al., 2019), 35-1200 mg/L (Yusuff & Sonibare, 2004), which were almost similar to the present findings indicating highly polluted effluents. For TDS, nearly similar studies have been conducted by a number of investigators (Hussein, 2013; Islam & Mostafa, 2020; Upadhye & Joshi, 2012), showing TDS to vary between 1500-6000, 1800-6000, and 2937.5-3778 mg/L, respectively which was relevant to

our results. Table 2 shows the concentration of Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, and PO_4^{3-}, which were higher than the DoE-BD standard. These effluents containing diverse pollutants present an unprecedented threat to the ecosystems and also to the surface and ground waters. Due to the adverse effects of untreated effluents on various ecosystems, removal of pollutants has become imperative (Islam et al., 2012). Based on the above experimental evidences it is concluded that all the parameters are high in concentration than the standard values given by DoE-BD. Hence the higher values are considered to be threatening to the environment as a result it is suggested that the dumping of effluents without ideal treatment should be avoided. Therefore, it is imperative to improve the treatment method to reduce the impact of the effluents on the environment. Nevertheless, we sought alternatives for optimization and improvement of the treatment through coagulation with $Al_2(SO_4)_3$ coagulant agents.

Table 1. Physicochemical parameters of the raw effluents

Parameters	Ef1	Ef2	Ef3	DoE-BD standards
pH	11.30	11.20	10.00	6.5-8.0
EC (μS/cm)	6240	6082	5280	1200
TSS (mg/L)	475	400	365	150
TDS (mg/L)	5160	4834	4235	2100
DO (mg/L)	1.4	1.6	1.8	4.5-8.0
COD (mg/L)	3732	3480	2980	200
BOD (mg/L)	1156	1065	964	50

Table 2. Concentration of anionic parameters in the textile dyeing effluents

Samples → Parameters ↓	Results			DoE-BD standard
	Ef1	Ef2	Ef3	
Cl^- (mg/L)	562.30	487.54	692.07	150-600
SO_4^{2-} (mg/L)	1775.26	1082.40	770.38	400
HCO_3^- (mg/L)	680.45	570.25	614.32	300
NO_3^- (mg/L)	45.05	27.84	37.56	10
PO_4^{3-} (mg/L)	26.45	35.65	18.48	25

3.2. Optimization of COD removal efficiency

Coagulation experiments were performed using a jar test apparatus containing six jars to optimize process parameters, including coagulant dosage, contact time, pH, and temperature. First, the experiments were performed

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without pH adjustment, and then the effects of pH on COD removal at optimized coagulant dosage were investigated. The results of the optimization parameters on the COD removal efficiency are stated below.

3.2.1. Effect of coagulant dose

Dose is one of the most crucial aspects to take into account in the C-F process when determining the optimal coagulant conditions. Basically, lower or higher doses will reduce flocculation performance. As a result, it's critical to figure out the best dose to get the best results from treatment while also keeping costs down. Figure 1depicts the effects of coagulant doses (100-1200 mg/L) on the COD removal efficiency of the effluents. The COD removal efficiency increases with the amount of dosage for all effluents due to high positive charge and polymeric effect of the coagulants (Joo et al., 2007). The results indicate that the COD removal efficiency increased gradually at first with doses up to 600, 700, and 500 mg/L for Ef1, Ef2, and Ef3, respectively. The COD-reducing trend declined after optimal dosage due to restabilising the colloids at higher doses. However, using optimal doses of 600, 700, and 500 mg/L, the maximum COD removal rates for the samples Ef1, Ef2, and Ef3 were 64.28%, 65.1%, and 63.45%, respectively. This is believed to be due to the hydrolysis of Al^{+3} during coagulation, resulting in monomeric aluminum hydrolyzed products like Al^{3+}, $Al(OH)^{2+}$, and $Al_3(OH)_6^{3+}$ in the solution (Giacobello et al.). Due to the precipitation of amorphous hydroxide, aluminum had controlled solubility. This precipitation causes sweep flocculation, in which impurities are effectively detached from the rising precipitates and become trapped there (Aguilar et al., 2005). In an experiment the highest removal of COD was 72.6% and 55.2% using alum and ferric sulfate, respectively (Patel & Vashi, 2010). Jindal et al. (Jindal et al., 2016) conducted a study on color and COD removal in textile effluents using C-F and illustrated that the COD removal efficiency of real textile wastewater was about 50% at a dose of 1000 mg/L. All these experiments mentioned above support the present findings.
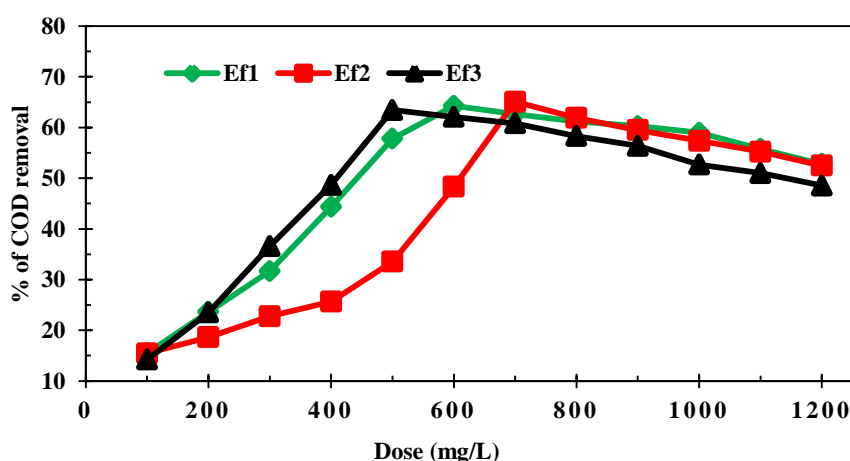

Figure 1. Effect of coagulant dosage on the COD removal efficiency of textile dyeing effluents [contact time 30 min, pH 11.30, temperature 30°C, mixing speed 45 rpm, and settling time 30 min]

3.2.2. Effect of contact time

Contact time plays an important role in floc formation and growth in the aggregation process. Coagulant spreads throughout the medium and adsorbs on the surfaces of the colloidal particles for charge neutralization or interparticle bridging during the mixing phase. The effect of contact time on coagulation was studied using a time

range of 15 minutes to 180 minutes, while other parameters remained constant. According to the trends depicted in Figure 2, either a longer or shorter contact time would result in subpar binding and bridging performance for all effluents. This is due to the inability of short-term collisions between flocculants and colloids to precipitate wastewater's suspended solids. The optimal contact time at which maximum COD removal achieved was 30 minutes for all effluents. With increasing reaction times from 30 minutes to 180 minutes, the COD removal efficiency decreased from 63.8% to 58.8%. 62.1% to 55.3%, and 63.6% to 58.5% for Ef1, Ef2, and Ef3, respectively. This is because longer mixing times increase floc breakage and limit the size of the flocs formed. Smaller flakes are less dense and indirectly re-turbid the sample (Hassan et al., 2009). This phenomenon is observed in Figure 2, which shows that longer contact times (i.e., 180 minutes) lead to lower COD reduction rates. The COD reduction rate was about 64% at a contact time of 30 minutes with an optimum dosage for almost all textile dyeing effluents.
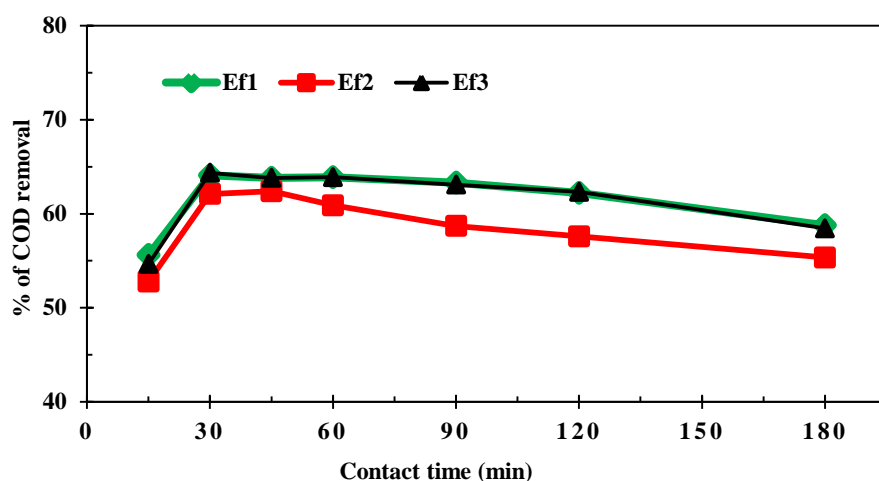

Figure 2. Effect of contact time on the COD removal efficiency of the effluents [dosage 600, 700, and 500 mg/L for Ef1, Ef2, and Ef3, respectively, temperature 30°C, mixing speed 45 rpm, and settling time 30 min]

3.2.3. Effect of pH

plays a significant role in influencing the COD removal efficiency of the inorganic coagulants used in the treatment of textile dyeing effluents. This is because the inorganic coagulant is converted into different ionic species as the pH value changes, thus influencing the coagulation (Rodrigues et al., 2013). The effect of pH on the COD removal efficiency was examined using optimum dose of coagulant at different pH ranges from 3.0 to 12.0 as shown in Figure 3. The pH affected the molecular structure of dyes, which in turn changed the COD test of the effluents. Aluminum salt react with water or with alkalinity prevailing in water. Liable upon pH these complexes exist in ionic form in the positive range at the lower pH values to negative at the higher pH values (Patel & Vashi, 2010). Figure 3 shows the percentage of COD removal increases with increase in pH from 3.0 to 11.0 for all the effluents. The optimum pH was 7.0 -11.0, 11.0, and 7.0 -11.0 for the samples Ef1, Ef2, and Ef3, respectively. The maximum COD removal efficiencies for Ef1, Ef2, and Ef3 were 64.1%, 64.2%, and 64.4%, respectively, at the optimum pH values. This result might be due to the coagulator advantages of $Al_2(SO_4)_3$ and its ability to form flocs quickly with larger and more rapid sedimentation (Gao et al., 2003). The Figure shows that the removal rate was initially low in the acid

range for Ef1 and Ef2, and the removal rate increased in the pH ranges from 3.0 to 7.0. This is because aluminum salts hydrolyze in the acidic range to form monomeric aluminum-hydrolyzed species. Soluble aluminum cations therefore play an important role in destabilizing negatively charged particles through charge neutralization. Alkaline pH maximizes the formation of aluminum cations and neutral $Al(OH)_2$ hydrolyzed species with large surface areas capable of adsorbing organic materials, inorganic particles and soluble dyes, resulting in color and COD removal has been done by charge neutralization and sweep flocculation (Perng & Bui, 2014; Stephenson & Duff, 1996; Suman et al., 2018). At other pH, the complexes of formed hydrolysis products caused the decrease of the removal efficiency (Perng & Bui, 2014). Therefore, $Al_2(SO_4)_3$ coagulant was more effective in a broader pH range from almost 7.0 to 11.0 for each effluent and the maximum COD was removed.
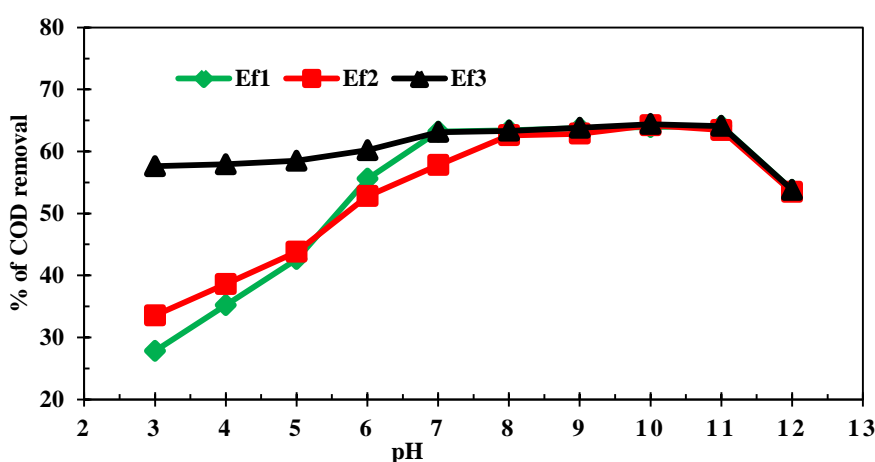

Figure 3. Effect of pH on the COD removal efficiency of the effluents

[coagulant dosage 600, 700, and 500 mg/L for Ef1, Ef2, and Ef3, respectively, contact time 30 min, temperature 30°C, mixing speed 45 rpm, and settling time 30 min]

3.2.4. Effect of temperature

Experiments were carried out at the optimum dose of coagulant, reaction time and pH keeping other parameters constant while varying the temperature from 25°C to 50°C to determine the optimum temperature for COD removal. As shown in Figure 4, when the temperature was increased from 25°C to 30°C, the COD removal rate abruptly increased to a maximum, and then shortly thereafter the COD removal rate decreased slowly with increasing temperature or remained constant after 30°C. The effect of low temperature on coagulation kinetics and flake surface morphology showed that low temperature decreased the solidification process as evidenced by a decrease in aggregation rate and rate constant (Xiao et al., 2009). Lower temperatures (0-24°C) have been reported to affect floc strength and effectively floc formation efficiency, resulting in lower flocculation rates and poor sedimentation (Fitzpatrick et al., 2004). Removal efficiency increases with temperature, as higher temperatures result in faster reaction rates. The improved performance at 30°C may be a result of the improved kinetics seen in most chemical reactions (Rodrigues et al., 2013). As the temperature increases from 25°C to 30°C, viscosity of the raw water decreases and brown movement become fierce gradually as a result of hydrolysis of Al^{3+} ion and increased competition for bonding by the macromolecules. This accelerates the coagulation processes (Misau &

Yusuf, 2016; Stephenson & Duff, 1996). As seen, the COD removal efficiency slowly decreased above 30°C for all effluents due to the fact that higher temperature increases flake breakage and decreases flake reformation. In general, higher temperatures produce larger flocs, which indicate weak floc deposition due to fragility and poor reformation. Higher temperatures (above 35°C) lead to greater fracturing in terms of floc size reduction (Brabty, 2006). As per Figure 4, the COD removal efficiencies were 65.3%, 65.8%, and 64.5% for Ef1, Ef2, and Ef3, respectively at optimum conditions, indicating suitability of $Al_2(SO_4)_3$ coagulant.
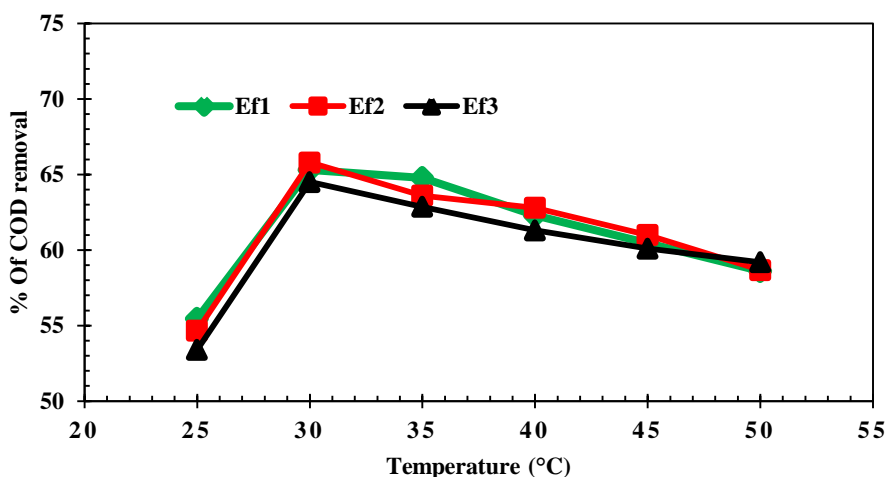

Figure 4. Effect of temperature on the COD removal efficiency of the effluents [dosage 600, 700, and 500 mg/L for Ef1, Ef2, and Ef3, respectively, contact time 30 min, pH 11.0, mixing speed 45 rpm, and settling time 30 min]

3.3. Removal Efficiency

3.3.1. Electrical Conductivity (EC)

Electrical conductivity measures the ability of water to conduct current carried by the various ions present in solution. Table 3 shows the conductivity of the samples before and after treatment. The EC values for samples Ef1, Ef2, and Ef3 were 6240, 6082, and 5280 μS/cm, approximately five times the maximum allowable limit (1200 μS/cm). This was because the wastewater contained large amounts of ionic substances released during textile processing in the study area owing to various inorganic substances. The EC value of the effluent is reduced to below DoE-BD standards (Table 3) after treatment, indicating the suitability of the coagulants. Figure 5 indicates the EC removal efficiencies were 86, 86 and 90% for Ef1, Ef2, and Ef3, respectively.

Table 3. Electrical conductivity of the effluents before and after treatment

Samples	EC (μS) before treatment	EC (μS) after treatment	DoE-BD standard
Ef1	6240	870	1200
Ef2	6082	845	
Ef3	5280	510	

3.3.2. Total Suspended Solids (TSS)

The TSS values were found 475, 400, and 365 mg/L before treatment for Ef1, Ef2, and Ef3, respectively which is notably higher than the permissible limit (150 mg/L) as per DoE-BD and EPA standard shown Table 4. TSS values of the effluents goes down to DoE-BD standard level after treatment with coagulants (Table 4). The removal efficiency of TSS was almost 90% for Ef1 and Ef3 and 80% for Ef2 as shown in Figure 5. Aleem et al. (Aleem et al., 2016) described that the percentage removal of TSS was about 62% of textile effluents of Pakistan, which was lower than the present findings.

3.3.3. Total Dissolved Solids (TDS)

As shown in Table 4, the TDS values in the raw effluents were found 4337, 4025, and 3482 mg/L for Ef1, Ef2, and Ef3. This may be due to the use of different chemicals, such as NaOH, Na_2CO_3 and inorganic salts during different stages of textile processing. Water with a high TDS is not drinkable and can be harmful to health and the environment.

Table 4. TSS and TDS of three textile effluents before and after treatment

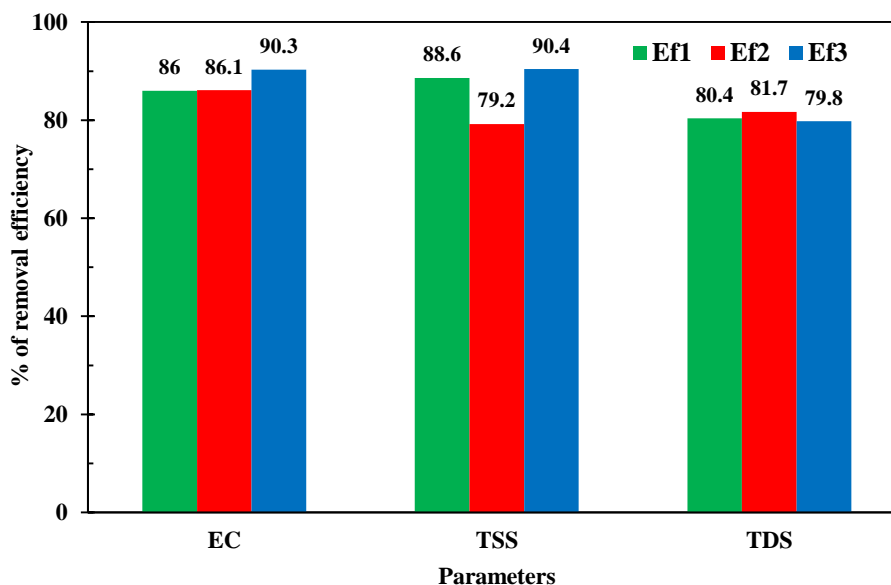| Sample	TSS (mg/L)		TDS (mg/L)	
	Before Treatment	After treatment	Before Treatment	After treatment
Ef1	475	54	4337	850
Ef2	400	83	4025	737
Ef3	365	35	3482	702
DoE-BD standard	150		910	

Figure 5. Percentage removal of EC, TSS, and TDS from effluents after treatment with $Al_2(SO_4)_3$ coagulant

One study found an acceptable TDS range of 1850 to 2000 mg/L for agricultural uses (Kumar, 1989). Low molecular weight organic bases from the dye industry may have dissolved as the pH of the samples was higher, resulting in higher TDS values (Momtaz et al., 2012). Hence, TDS levels in the research area were high due to the high pH value. Table 4 & Figure 5 show that the TDS values of wastewater after treatment with $Al_2(SO_4)_3$ coagulant decreased below DoE-BD standards, with a removal efficiency of approximately 80%.

3.3.4. Chemical Oxygen Demand (COD)

COD is the quantity of oxygen required to oxidize the organic material present in a given volume of water sample. As shown Table 5, the COD values of the effluents before treatment were 3732, 3480, and 2980 mg/L for Ef1, Ef2, Ef3, respectively. The findings were 15 to 19 times higher than the DoE- BD standard (200 mg/L) indicating high level of pollution. Higher COD values were due to the presence of oxidizable compounds used in various steps of textiles processing. A study observed that the COD value of real textile wastewater collected from textile factory in Baghdad was varied from 150 to 10^4 mg/L (Hussein, 2013). In another experiment, the COD values of three effluents collected from Narsingdi, Rajshahi, and Gazipur district of Bangladesh were found 784, 340, and 512 mg/L, respectively, which were much lower compared to the present findings (Islam & Mostafa, 2020). The COD values after treatment are tabulated in Table 5. Moreover, Figure 6 shows the percent of COD removal efficiencies are 65%, 66%, and 64.5% for Ef1, Ef2, and Ef3, respectively.

Table 5. COD and BOD of the effluents before and after treatment

Samples	COD (mg/L)		BOD (mg/L)	
	Before treatment	After treatment	Before treatment	After treatment
Ef1	3732	1488	1156	328
Ef2	3480	1351	1065	304
Ef3	2980	1102	964	248
DoE- BD standard	200		50	

3.3.5. Biological Oxygen Demand (BOD$_5$)

The amount of dissolved oxygen (DO) required by aerobic biological organisms to decompose organic material present in a given water sample at a particular temperature over a certain time period is known as BOD$_5$. The results showed that the BOD values of the effluents were 1156, 1065, and 964 mg/L for Ef1, Ef2, and Ef3, respectively, as shown in Table 5 indicating highly polluted effluents. The BOD$_5$ results of the present study revealed that the effluents were in the worst conditions indicating a heavily contaminated industrial area. Figure 6 indicates that about 72%, 72% and 74% BOD were removed from Ef1, Ef2, and Ef3, respectively after treatment with $Al_2(SO_4)_3$ coagulant. Patel and Vashi (Patel & Vashi, 2010) determined that the BOD of textile effluent was reduced to 51.4% after treatment with ferric sulfate coagulant which is lower than the present findings.
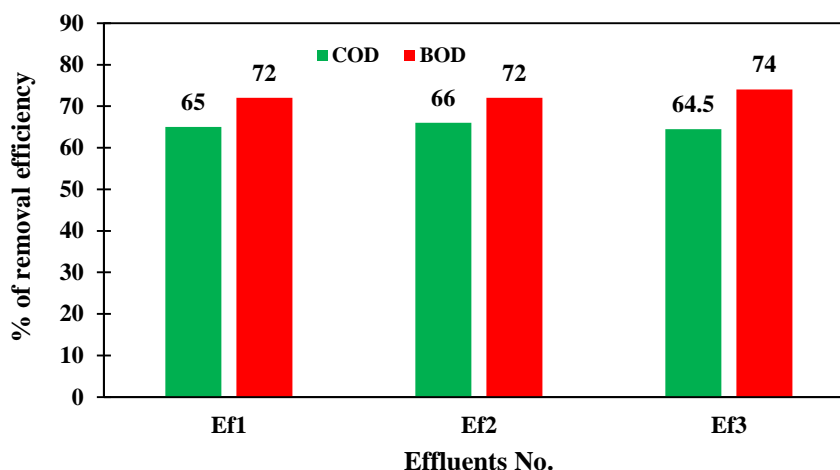
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Figure 6. Percentage of COD & BOD removal efficiency with $Al_2(SO_4)_3$ coagulants

▨ 4. Conclusions

The effluents discharged from textile industries are a mixture of dyes, metals, and other pollutants. So, the study was targeted to characterize and treat the textile dyeing effluent before discharging it into the adjacent water bodies. The collected samples were analyzed for some physicochemical parameters, including pH, DO, EC, TSS, TDS, COD, and BOD to evaluate the pollution loads in water streams where the discharge effluent entered. In addition, some anions, such as Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, and PO_4^{3-} were measured in the samples. The analysis results showed that the textile dyeing effluent was highly alkaline, and parameters like EC, TSS, TDS, COD, BOD, and some anions were found to be higher than the DoE-BD standard guidelines for effluent discharge. In this study, coagulant dosage, pH, reaction time, and temperature were optimized for the removal of COD and other physicochemical parameters from the effluents using the coagulation–flocculation process. The study optimized the process parameters of the coagulation and illustrated that $Al_2(SO_4)_3$ coagulant potentially reduced TDS, TSS, BOD, and COD from the effluents. The study observed that the highest removal of COD and BOD was 66% and 74% for the samples Ef2 and Ef3, respectively. The highest TSS removal rate was around 90% for Ef3 and almost 80% TDS removals were achieved for Ef1, Ef2, and Ef3, respectively. The results indicated that the $Al_2(SO_4)_3$ showed a better coagulant efficiency for reducing the concentration of several physicochemical parameters in wastewater, and the treated effluent satisfied the DoE-BD standards for discharging wastewater into the public sewage network. It is difficult to degrade the dyeing effluent using a single treatment unit, such as a physical, chemical, or biological process. Therefore, the study suggested a combination of the physical and chemical processes, i.e.; coagulation combined with adsorption, for achieving higher degradation of the effluents. Further work should be considered based on the best coagulant-dye combinations for achieving maximum color removal efficiency for a specific dye group.

Competing Interests Statement

The authors declare the total absence of conflicts of interest, both during the conduct of the study and during the written drafting of this work.

Consent for Publication

The authors declare that they consented to the publication of this research work.

Authors' Contributions

Both authors took part in literature review, experimentation, and manuscript writing equally.

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